

**BIRCH, STEWART, KOLASCH & BIRCH, LLP**

**INTELLECTUAL PROPERTY LAW**

**8110 GATEHOUSE ROAD**

**SUITE 500 EAST**

**FALLS CHURCH, VA 22042-1210**

**USA**

**(703) 205-8000**

**FAX (703) 205-8050**

**(703) 698-8590 (G IV)**

**e-mail: mailroom@bskb.com**

**web: http://www.bskb.com**

**CALIFORNIA OFFICE  
COSTA MESA, CALIFORNIA**

THOMAS S. AUCHTERLE  
JAMES T. ELLER, JR.  
SCOTT L. LOWE  
MARK J. NUEL, PH.D.  
D. RICHARD ANDERSON  
PAUL C. LEWIS  
MARK W. MILSTEAD\*  
RICHARD J. GALLAGHER  
JAYNE M. SAYDAH\*  
MARYANNE ARMSTRONG, PH.D.  
HYUNG N. SOHN  
ALAN PEDERSEN-GILES  
KECIA J. REYNOLDS

REG. PATENT AGENTS.  
FREDERICK R. HANDREN  
MAKI HATSUMI  
MIKE S. RYU  
CRAIG A. McROBBIE  
GARTH M. DAHLEN, PH.D.  
ROBERT E. GOOZNER, PH.D.  
MATTHEW J. LATTIG  
TIMOTHY R. WYCKOFF  
KRISTI L. RUPERT, PH.D.  
LARRY J. HUME  
ALBERT K. LEE  
HRAYR A. SAYADIAN, PH.D.  
EVE L. FRANK, PH.D.  
MATTHEW T. SHANLEY

TERRELL C. BIRCH  
RAYMOND C. STEWART  
JOSEPH A. KOLASCH  
JAMES M. SLATTERY  
BERNARD L. SWEENEY\*  
MICHAEL K. MUTTER  
CHARLES GORENSTEIN  
GERALD M. MURPHY, JR.  
LEONARD R. SVENSSON  
TERRY L. CLARK  
ANDREW D. MEIKLE  
MARC S. WEINER  
JOE MCKINNEY MUNCY  
ROBERT J. KENNEY  
DONALD J. DALEY  
JOHN W. BAILEY  
JOHN A. CASTELLANO  
GARY D. YACURA

OF COUNSEL  
HERBERT M. BIRCH (1905-1996)  
ELLIOT A. GOLDBERG\*  
WILLIAM L. GATES\*  
EDWARD H. VALANCE  
RUPERT J. BRADY (RET)\*  
F. PRINCE BUTLER  
FRED S. WHISENHUNT

\*ADMITTED TO A BAR OTHER THAN VA

Date: November 21, 2000

Docket No.: 1920-0115P

Assistant Commissioner for Patents  
Box PATENT APPLICATION  
Washington, D.C. 20231

Sir:

Transmitted herewith for filing is the patent application of

Inventor(s): SOKOLOV, Skiff

For: NOISE REDUCTION IN IMAGES

Enclosed are:

X A specification consisting of 24 pages

          sheet(s) of      drawings

X An assignment of the invention

X Certified copy of Priority Document(s)

X Executed Declaration X Original      Photocopy

X Applicant claims small entity status in accordance with 37 CFR 1.27

     Application Data Sheet in accordance with 37 C.F.R. 1.76

     Preliminary Amendment

X Information Disclosure Statement, PTO-1449 and reference(s)

\_\_\_ Other \_\_\_\_\_

\_\_\_ Applicant requests early publication

The filing fee has been calculated as shown below:

## LARGE ENTITY

## SMALL ENTITY

FOR	NO. FILED	NO. EXTRA	RATE	FEE		RATE	FEE
BASIC FEE	***** ***** *****	***** ***** *****	***** ***** *****	\$710.00	or	**** **** ****	\$355.00
TOTAL CLAIMS	20 - 20 =	0	x18 = \$	0.00	or	x 9 = \$	0.00
INDEPENDENT	3 - 3 =	0	x80 = \$	0.00	or	x 40 = \$	0.00
MULTIPLE DEPENDENT CLAIM PRESENTED <u>yes</u>			+270 = \$	0.00	or	+135 = \$	135.00

TOTAL \$ 0.00

TOTAL \$ 490.00

RECEIVED

X A check in the amount of \$ 530.00 to cover the filing fee and recording fee (if applicable) is enclosed.

\_\_\_ Please charge Deposit Account No. 02-2448 in the amount of \$ \_\_\_\_\_. A triplicate copy of this transmittal form is enclosed.

\_\_\_ No fee is enclosed.

If necessary, the Commissioner is hereby authorized in this, concurrent, and future replies, to charge payment or credit any overpayment to Deposit Account No. 02-2448 for any additional fees required under 37 C.F.R. 1.16 or under 37 C.F.R. 1.17; particularly, extension of time fees.

Respectfully submitted,

BIRCH, STEWART, KOLASCH & BIRCH, LLP

By \_\_\_\_\_

JOHN CASTELLANO

Reg. No. 35,094

P. O. Box 747

Falls Church, Virginia 22040-0747

STATEMENT CLAIMING SMALL ENTITY STATUS  
(37 CFR 1.9(f) & 1.27(c)) - SMALL BUSINESS CONCERN

Docket Number: 1920-0115P

Applicant, Patentee, or Identifier: Tom Francke

Application or Patent No.: New

Filed or Issued: November 21, 2000

Title: NOISE REDUCTION IN IMAGES

I hereby state that I am

- ☐ the owner of the small business concern identified below:  
☒ an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF SMALL BUSINESS CONCERN XCounter AB

ADDRESS OF SMALL BUSINESS CONCERN Svärdvägen 3B, SE-182 33 Danderyd, Sweden

I hereby state that the above identified small business concern qualifies as a small business concern as defined in 37 CFR Part 121 for purposes of paying reduced fees to the United States Patent and Trademark Office, in that the number of employees of the concern, including those of its affiliates does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time part-time, or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby state that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention described in:

- ☒ the specification filed herewith with title as listed above.  
☐ the application identified above.  
☐ the patent identified above.

If the rights held by the above identified small business concern are not exclusive, each individual, concern, or organization having rights in the invention must file separate statements as to their status as small entities, and no rights to the invention are held by any person, other than the inventor, who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person made the invention, or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d), or a nonprofit organization under 37 CFR 1.9(e).

Each person, concern, or organization having any rights in the invention is listed below:

- ☒ no such person, concern, or organization exists.  
☐ each such person, concern, or organization is listed below.

Separate statements are required from each named person, concern, or organization having rights to the invention stating their status as small entities. (37 CFR 1.27)

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is not longer appropriate. (37 CFR 1.28(b))

NAME OF PERSON SIGNING Tom Francke

TITLE IN ORGANIZATION OF PERSON SIGNING President

ADDRESS OF PERSON SIGNING Hemgårdsvägen 2, SE-191 44 Sollentuna, Sweden

SIGNATURE Tom Francke

DATE 20 Sept 2000

PATENT- OCH REGISTRERINGSVERKET  
Patentavdelningen

## Intyg Certificate

Härmed intygas att bifogade kopior överensstämmer med de handlingar som ursprungligen ingivits till Patent- och registreringsverket i nedannämnda ansökan.

*This is to certify that the annexed is a true copy of the documents as originally filed with the Patent- and Registration Office in connection with the following patent application.*

- |      |   |                                 |
|------|---|---------------------------------|
| (71) | Sökande<br>Applicant                                | Xcounter AB, Danderyd SE<br>(s) |
| (21) | Patentansökningsnummer<br>Patent application number | 0003608-7                       |
| (86) | Ingivningsdatum<br>Date of filing                   | 2000-10-06                      |

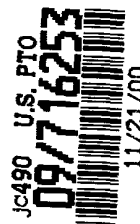
Stockholm, 2000-10-18

*För Patent- och registreringsverket*  
*For the Patent- and Registration Office*

Anita Södervall  
Anita Södervall

*Avgift*  
*Fee* 170:-

BSKB 103-205 BOX  
SOKOLOV, SKIFF  
1920- OLSP  
1051



## NOISE REDUCTION IN IMAGES

### FIELD OF INVENTION

The present invention relates generally to noise reduction, and specifically to noise reduction in digital images.

### 5 BACKGROUND

001  
002  
003  
004  
005  
006  
007  
008  
009  
010  
011  
012  
013  
014  
015  
016  
017  
018  
019  
020  
021  
022  
023  
024  
025  
026  
027  
028  
029  
030  
031  
032  
033  
034  
035  
036  
037  
038  
039  
040  
041  
042  
043  
044  
045  
046  
047  
048  
049  
050  
051  
052  
053  
054  
055  
056  
057  
058  
059  
060  
061  
062  
063  
064  
065  
066  
067  
068  
069  
070  
071  
072  
073  
074  
075  
076  
077  
078  
079  
080  
081  
082  
083  
084  
085  
086  
087  
088  
089  
090  
091  
092  
093  
094  
095  
096  
097  
098  
099  
100  
101  
102  
103  
104  
105  
106  
107  
108  
109  
110  
111  
112  
113  
114  
115  
116  
117  
118  
119  
120  
121  
122  
123  
124  
125  
126  
127  
128  
129  
130  
131  
132  
133  
134  
135  
136  
137  
138  
139  
140  
141  
142  
143  
144  
145  
146  
147  
148  
149  
150  
151  
152  
153  
154  
155  
156  
157  
158  
159  
160  
161  
162  
163  
164  
165  
166  
167  
168  
169  
170  
171  
172  
173  
174  
175  
176  
177  
178  
179  
180  
181  
182  
183  
184  
185  
186  
187  
188  
189  
190  
191  
192  
193  
194  
195  
196  
197  
198  
199  
200  
201  
202  
203  
204  
205  
206  
207  
208  
209  
210  
211  
212  
213  
214  
215  
216  
217  
218  
219  
220  
221  
222  
223  
224  
225  
226  
227  
228  
229  
230  
231  
232  
233  
234  
235  
236  
237  
238  
239  
240  
241  
242  
243  
244  
245  
246  
247  
248  
249  
250  
251  
252  
253  
254  
255  
256  
257  
258  
259  
260  
261  
262  
263  
264  
265  
266  
267  
268  
269  
270  
271  
272  
273  
274  
275  
276  
277  
278  
279  
280  
281  
282  
283  
284  
285  
286  
287  
288  
289  
290  
291  
292  
293  
294  
295  
296  
297  
298  
299  
300  
301  
302  
303  
304  
305  
306  
307  
308  
309  
310  
311  
312  
313  
314  
315  
316  
317  
318  
319  
320  
321  
322  
323  
324  
325  
326  
327  
328  
329  
330  
331  
332  
333  
334  
335  
336  
337  
338  
339  
340  
341  
342  
343  
344  
345  
346  
347  
348  
349  
350  
351  
352  
353  
354  
355  
356  
357  
358  
359  
360  
361  
362  
363  
364  
365  
366  
367  
368  
369  
370  
371  
372  
373  
374  
375  
376  
377  
378  
379  
380  
381  
382  
383  
384  
385  
386  
387  
388  
389  
390  
391  
392  
393  
394  
395  
396  
397  
398  
399  
400  
401  
402  
403  
404  
405  
406  
407  
408  
409  
410  
411  
412  
413  
414  
415  
416  
417  
418  
419  
420  
421  
422  
423  
424  
425  
426  
427  
428  
429  
430  
431  
432  
433  
434  
435  
436  
437  
438  
439  
440  
441  
442  
443  
444  
445  
446  
447  
448  
449  
450  
451  
452  
453  
454  
455  
456  
457  
458  
459  
460  
461  
462  
463  
464  
465  
466  
467  
468  
469  
470  
471  
472  
473  
474  
475  
476  
477  
478  
479  
480  
481  
482  
483  
484  
485  
486  
487  
488  
489  
490  
491  
492  
493  
494  
495  
496  
497  
498  
499  
500  
501  
502  
503  
504  
505  
506  
507  
508  
509  
510  
511  
512  
513  
514  
515  
516  
517  
518  
519  
520  
521  
522  
523  
524  
525  
526  
527  
528  
529  
530  
531  
532  
533  
534  
535  
536  
537  
538  
539  
540  
541  
542  
543  
544  
545  
546  
547  
548  
549  
550  
551  
552  
553  
554  
555  
556  
557  
558  
559  
560  
561  
562  
563  
564  
565  
566  
567  
568  
569  
570  
571  
572  
573  
574  
575  
576  
577  
578  
579  
580  
581  
582  
583  
584  
585  
586  
587  
588  
589  
590  
591  
592  
593  
594  
595  
596  
597  
598  
599  
600  
601  
602  
603  
604  
605  
606  
607  
608  
609  
610  
611  
612  
613  
614  
615  
616  
617  
618  
619  
620  
621  
622  
623  
624  
625  
626  
627  
628  
629  
630  
631  
632  
633  
634  
635  
636  
637  
638  
639  
640  
641  
642  
643  
644  
645  
646  
647  
648  
649  
650  
651  
652  
653  
654  
655  
656  
657  
658  
659  
660  
661  
662  
663  
664  
665  
666  
667  
668  
669  
670  
671  
672  
673  
674  
675  
676  
677  
678  
679  
680  
681  
682  
683  
684  
685  
686  
687  
688  
689  
690  
691  
692  
693  
694  
695  
696  
697  
698  
699  
700  
701  
702  
703  
704  
705  
706  
707  
708  
709  
710  
711  
712  
713  
714  
715  
716  
717  
718  
719  
720  
721  
722  
723  
724  
725  
726  
727  
728  
729  
730  
731  
732  
733  
734  
735  
736  
737  
738  
739  
740  
741  
742  
743  
744  
745  
746  
747  
748  
749  
750  
751  
752  
753  
754  
755  
756  
757  
758  
759  
760  
761  
762  
763  
764  
765  
766  
767  
768  
769  
770  
771  
772  
773  
774  
775  
776  
777  
778  
779  
780  
781  
782  
783  
784  
785  
786  
787  
788  
789  
790  
791  
792  
793  
794  
795  
796  
797  
798  
799  
800  
801  
802  
803  
804  
805  
806  
807  
808  
809  
810  
811  
812  
813  
814  
815  
816  
817  
818  
819  
820  
821  
822  
823  
824  
825  
826  
827  
828  
829  
830  
831  
832  
833  
834  
835  
836  
837  
838  
839  
840  
841  
842  
843  
844  
845  
846  
847  
848  
849  
850  
851  
852  
853  
854  
855  
856  
857  
858  
859  
860  
861  
862  
863  
864  
865  
866  
867  
868  
869  
870  
871  
872  
873  
874  
875  
876  
877  
878  
879  
880  
881  
882  
883  
884  
885  
886  
887  
888  
889  
890  
891  
892  
893  
894  
895  
896  
897  
898  
899  
900  
901  
902  
903  
904  
905  
906  
907  
908  
909  
910  
911  
912  
913  
914  
915  
916  
917  
918  
919  
920  
921  
922  
923  
924  
925  
926  
927  
928  
929  
930  
931  
932  
933  
934  
935  
936  
937  
938  
939  
940  
941  
942  
943  
944  
945  
946  
947  
948  
949  
950  
951  
952  
953  
954  
955  
956  
957  
958  
959  
960  
961  
962  
963  
964  
965  
966  
967  
968  
969  
970  
971  
972  
973  
974  
975  
976  
977  
978  
979  
980  
981  
982  
983  
984  
985  
986  
987  
988  
989  
990  
991  
992  
993  
994  
995  
996  
997  
998  
999  
1000  
1001  
1002  
1003  
1004  
1005  
1006  
1007  
1008  
1009  
1010  
1011  
1012  
1013  
1014  
1015  
1016  
1017  
1018  
1019  
1020  
1021  
1022  
1023  
1024  
1025  
1026  
1027  
1028  
1029  
1030  
1031  
1032  
1033  
1034  
1035  
1036  
1037  
1038  
1039  
1040  
1041  
1042  
1043  
1044  
1045  
1046  
1047  
1048  
1049  
1050  
1051  
1052  
1053  
1054  
1055  
1056  
1057  
1058  
1059  
1060  
1061  
1062  
1063  
1064  
1065  
1066  
1067  
1068  
1069  
1070  
1071  
1072  
1073  
1074  
1075  
1076  
1077  
1078  
1079  
1080  
1081  
1082  
1083  
1084  
1085  
1086  
1087  
1088  
1089  
1090  
1091  
1092  
1093  
1094  
1095  
1096  
1097  
1098  
1099  
1100  
1101  
1102  
1103  
1104  
1105  
1106  
1107  
1108  
1109  
1110  
1111  
1112  
1113  
1114  
1115  
1116  
1117  
1118  
1119  
1120  
1121  
1122  
1123  
1124  
1125  
1126  
1127  
1128  
1129  
1130  
1131  
1132  
1133  
1134  
1135  
1136  
1137  
1138  
1139  
1140  
1141  
1142  
1143  
1144  
1145  
1146  
1147  
1148  
1149  
1150  
1151  
1152  
1153  
1154  
1155  
1156  
1157  
1158  
1159  
1160  
1161  
1162  
1163  
1164  
1165  
1166  
1167  
1168  
1169  
1170  
1171  
1172  
1173  
1174  
1175  
1176  
1177  
1178  
1179  
1180  
1181  
1182  
1183  
1184  
1185  
1186  
1187  
1188  
1189  
1190  
1191  
1192  
1193  
1194  
1195  
1196  
1197  
1198  
1199  
1200  
1201  
1202  
1203  
1204  
1205  
1206  
1207  
1208  
1209  
1210  
1211  
1212  
1213  
1214  
1215  
1216  
1217  
1218  
1219  
1220  
1221  
1222  
1223  
1224  
1225  
1226  
1227  
1228  
1229  
1230  
1231  
1232  
1233  
1234  
1235  
1236  
1237  
1238  
1239  
1240  
1241  
1242  
1243  
1244  
1245  
1246  
1247  
1248  
1249  
1250  
1251  
1252  
1253  
1254  
1255  
1256  
1257  
1258  
1259  
1260  
1261  
1262  
1263  
1264  
1265  
1266  
1267  
1268  
1269  
1270  
1271  
1272  
1273  
1274  
1275  
1276  
1277  
1278  
1279  
1280  
1281  
1282  
1283  
1284  
1285  
1286  
1287  
1288  
1289  
1290  
1291  
1292  
1293  
1294  
1295  
1296  
1297  
1298  
1299  
1300  
1301  
1302  
1303  
1304  
1305  
1306  
1307  
1308  
1309  
1310  
1311  
1312  
1313  
1314  
1315  
1316  
1317  
1318  
1319  
1320  
1321  
1322  
1323  
1324  
1325  
1326  
1327  
1328  
1329  
1330  
1331  
1332  
1333  
1334  
1335  
1336  
1337  
1338  
1339  
1340  
1341  
1342  
1343  
1344  
1345  
1346  
1347  
1348  
1349  
1350  
1351  
1352  
1353  
1354  
1355  
1356  
1357  
1358  
1359  
1360  
1361  
1362  
1363  
1364  
1365  
1366  
1367  
1368  
1369  
1370  
1371  
1372  
1373  
1374  
1375  
1376  
1377  
1378  
1379  
1380  
1381  
1382  
1383  
1384  
1385  
1386  
1387  
1388  
1389  
1390  
1391  
1392  
1393  
1394  
1395  
1396  
1397  
1398  
1399  
1400  
1401  
1402  
1403  
1404  
1405  
1406  
1407  
1408  
1409  
1410  
1411  
1412  
1413  
1414  
1415  
1416  
1417  
1418  
1419  
1420  
1421  
1422  
1423  
1424  
1425  
1426  
1427  
1428  
1429  
1430  
1431  
1432  
1433  
1434  
1435  
1436  
1437  
1438  
1439  
1440  
1441  
1442  
1443  
1444  
1445  
1446  
1447  
1448  
1449  
1450  
1451  
1452  
1453  
1454  
1455  
1456  
1457  
1458  
1459  
1460  
1461  
1462  
1463  
1464  
1465  
1466  
1467  
1468  
1469  
1470  
1471  
1472  
1473  
1474  
1475  
1476  
1477  
1478  
1479  
1480  
1481  
1482  
1483  
1484  
1485  
1486  
1487  
1488  
1489  
1490  
1491  
1492  
1493  
1494  
1495  
1496  
1497  
1498  
1499  
1500  
1501  
1502  
1503  
1504  
1505  
1506  
1507  
1508  
1509  
1510  
1511  
1512  
1513  
1514  
1515  
1516  
1517  
1518  
1519  
1520  
1521  
1522  
1523  
1524  
1525  
1526  
1527  
1528  
1529  
1530  
1531  
1532  
1533  
1534  
1535  
1536  
1537  
1538  
1539  
1540  
1541  
1542  
1543  
1544  
1545  
1546  
1547  
1548  
1549  
1550  
1551  
1552  
1553  
1554  
1555  
1556  
1557  
1558  
1559  
1560  
1561  
1562  
1563  
1564  
1565  
1566  
1567  
1568  
1569  
1570  
1571  
1572  
1573  
1574  
1575  
1576  
1577  
1578  
1579  
1580  
1581  
1582  
1583  
1584  
1585  
1586  
1587  
1588  
1589  
1590  
1591  
1592  
1593  
1594  
1595  
1596  
1597  
1598  
1599  
1600  
1601  
1602  
1603  
1604  
1605  
1606  
1607  
1608  
1609  
1610  
1611  
1612  
1613  
1614  
1615  
1616  
1617  
1618  
1619  
1620  
1621  
1622  
1623  
1624  
1625  
1626  
1627  
1628  
1629  
1630  
1631  
1632  
1633  
1634  
1635  
1636  
1637  
1638  
1639  
1640  
1641  
1642  
1643  
1644  
1645  
1646  
1647  
1648  
1649  
1650  
1651  
1652  
1653  
1654  
1655  
1656  
1657  
1658  
1659  
1660  
1661  
1662  
1663  
1664  
1665  
1666  
1667  
1668  
1669  
1670  
1671  
1672  
1673  
1674  
1675  
1676  
1677  
1678  
1679  
1680  
1681  
1682  
1683  
1684  
1685  
1686  
1687  
1688  
1689  
1690  
1691  
1692  
1693  
1694  
1695  
1696  
1697  
1698  
1699  
1700  
1701  
1702  
1703  
1704  
1705  
1706  
1707  
1708  
1709  
1710  
1711  
1712  
1713  
1714  
1715  
1716  
1717  
1718  
1719  
1720  
1721  
1722  
1723  
1724  
1725  
1726  
1727  
1728  
1729  
1730  
1731  
1732  
1733  
1734  
1735  
1736  
1737  
1738  
1739  
1740  
1741  
1742  
1743  
1744  
1745  
1746  
1747  
1748  
1749  
1750  
1751  
1752  
1753  
1754  
1755  
1756  
1757  
1758  
1759  
1760  
1761  
1762  
1763  
1764  
1765  
1766  
1767  
1768  
1769  
1770  
1771  
1772  
1773  
1774  
1775  
1776  
1777  
1778  
1779  
1780  
1781  
1782  
1783  
1784  
1785  
1786  
1787  
1788  
1789  
1790  
1791  
1792  
1793  
1794  
1795  
1796  
1797  
1798  
1799  
1800  
1801  
1802  
1803  
1804  
1805  
1806  
1807  
1808  
1809  
1810  
1811  
1812  
1813  
1814  
1815  
1816  
1817  
1818  
1819  
1820  
1821  
1822  
1823  
1824  
1825  
1826  
1827  
1828  
1829  
1830  
1831  
1832  
1833  
1834  
1835  
1836  
1837  
1838  
1839  
1840  
1841  
1842  
1843  
1844  
1845  
1846  
1847  
1848  
1849  
1850  
1851  
1852  
1853  
1854  
1855  
1856  
1857  
1858  
1859  
1860  
1861  
1862  
1863  
1864  
1865  
1866  
1867  
1868  
1869  
1870  
1871  
1872  
1873  
1874  
1875  
1876  
1877  
1878  
1879  
1880  
1881  
1882  
1883  
1884  
1885  
1886  
1887  
1888  
1889  
1890  
1891  
1892  
1893  
1894  
1895  
1896  
1897  
1898  
1899  
1900  
1901  
1902  
1903  
1904  
1905  
1906  
1907  
1908  
1909  
1910  
1911  
1912  
1913  
1914  
1915  
1916  
1917  
1918  
1919  
1920  
1921  
1922  
1923  
1924  
1925  
1926  
1927  
1928  
1929  
1930  
1931  
1932  
1933  
1934  
1935  
1936  
1937  
1938  
1939  
1940  
1941  
1942  
1943  
1944  
1945  
1946  
1947  
1948  
1949  
1950  
1951  
1952  
1953  
1954  
1955  
1956  
1957  
1958  
1959  
1960  
1961  
1962  
1963  
1964  
1965  
1966  
1967  
1968  
1969  
1970  
1971  
1972  
1973  
1974  
1975  
1976  
1977  
1978  
1979  
1980  
1981  
1982  
1983  
1984  
1985  
1986  
1987  
1988  
1989  
1990  
1991  
1992  
1993  
1994  
1995  
1996  
1997  
1998  
1999  
2000  
2001  
2002  
2003  
2004  
2005  
2006  
2007  
2008  
2009  
2010  
2011  
2012  
2013  
2014  
2015  
2016  
2017  
2018  
2019  
2020  
2021  
2022  
2023  
2024  
2025  
2026  
2027  
2028  
2029  
2030  
2031  
2032  
2033  
2034  
2035  
2036  
2037  
2038  
2039  
2040  
2041  
2042  
2043  
2044  
2045  
2046  
2047  
2048  
2049  
2050  
2051  
2052  
2053  
2054  
2055  
2056  
2057  
2058  
2059  
2060  
2061  
2062  
2063  
2064  
2065  
2066  
2067  
2068  
2069  
2070  
2071  
2072  
2073  
2074  
2075  
2076  
2077  
2078  
2079  
2080  
2081  
2082  
2083  
2084  
2085  
2086  
2087  
2088  
2089  
2090  
2091  
2092  
2093  
2094  
2095  
2096  
2097  
2098  
2099  
2100  
2101  
2102  
2103  
2104  
2105  
2106  
2107  
2108  
2109  
2110  
2111  
2112  
2113  
2114  
2115  
2116  
2117  
2118  
2119  
2120  
2121  
2122  
2123  
2124  
2125  
2126  
2127  
2128  
2129  
2130  
2131  
2132  
2133  
2134  
2135  
2136  
2137  
2138  
2139  
2140  
2141  
2142  
2143  
2144  
2145  
2146  
2147  
2148  
2149  
2150  
2151  
2152  
2153  
2154  
2155  
2156  
2157  
2158  
2159  
2160  
2161  
2162  
2163  
2164  
2165  
2166  
2167  
2168  
2169  
2170  
2171  
2172  
2173  
2174  
2175  
2176  
2177  
2178  
2179  
2180  
2181  
2182  
2183  
2184  
2185  
2186  
2187  
2188  
2189  
2190  
2191  
2192  
21

An advantage of the present invention is achieved by utilization of different methods in dependence on information known of noise or image structure, whereby improved noise reduction is achieved in accordance with said information.

5 Further features and advantages of the present invention will be evident from the following description.

#### DETAILED DESCRIPTION OF EMBODIMENTS

0044531-1200  
10 In the following description, for purpose of explanation and not limitation, specific details are set forth, such as particular techniques and applications in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced in other embodiment that depart from these specific details. In other instances, detailed  
15 descriptions of well-known methods and apparatuses are omitted so as not to obscure the description of the present invention with unnecessary details.

The present invention can, if some additional information about noise or image structure, besides the image itself, is  
20 given, be used to improve noise reduction and reduce the image-degrading consequence incurred by the noise reduction. Four important examples of such additional information is the knowledge that an image has one or several of the following properties:

25 (a) almost all the area of the true image, i.e. of the noise free image, is covered by many-pixel fragments, wherein the intensity is changing smoothly;

(b) the dispersion or other parameters of noise reduction, such as FWHM (full width at half maximum), are approximately  
30 known;

(c) the noise in the image is significantly correlated with the noise in other images (or in different parts of the same image); and

(d) the image is computed (reconstructed) from source data,  
5 which are common to source data of other images.

Most images have property (a), though the sizes and shapes of smooth fragments may vary much from image to image.

Property (b) is valid for most noisy images, including X-ray pictures.

10 Properties (c) and (d) are valid for most reconstructed images, including tomographic images and maps of bone density reconstructed from dual-energy X-ray images.

Although the noise in an image may be correlated with the noise in other images or portions thereof for many technical  
15 reasons, the most frequent cause of such correlation is the origin of images from the same source data. When several images are computed (reconstructed) from the same data, the same initial noise enters into all the computed images thereby making the noise, obtained by reconstruction,  
20 correlated.

The noise in reconstructed images is usually strongly amplified compared to the noise in source data and becomes an imminent problem, which can be solved by the methods of the present invention as will be described below. An important  
25 example is the calculation of bone and soft tissue densities from two X-ray images of the same part of body, but made with X-rays of different energies. Since the reconstruction of the densities is based on the small differences between such X-ray images, the reconstructed densities are very sensitive to  
30 the noise in these source images and the noises in the

reconstructed images are relatively large and are strongly correlated with each other.

The properties (a), (b), (c), and (d) give new possibilities of noise reduction which were not fully exploited before.

5 Methods of noise reduction will be described which using properties (a), (b), (c), and (d) accomplish deeper noise reduction and diminish the smearing consequence incurred by it. Especially deep noise reduction without any smearing of small details is achievable for the reconstructed images when  
10 methods using properties (a), (b), (c), and (d) are combined.

Noise in an image is generally any contamination dirt covering the true-image of the object of interest. The shapes of dirt fragments and the statistical properties of dirt may be quite different. The present invention concerns mainly the  
15 noise, which looks as dark and light spots or grains scattered over the whole image and covering it densely. If the image of the same or different object is produced again, e.g. another X-ray image taken of a patient, these spots lie at different places in that image than in the first image.

20 The high-frequency noise in pixel images consists of small spots of the size of one or two pixels. Such noise is often seen in images made by high sensitive films and electronic cameras made in conditions of poor illumination or low X-ray flux, when the number of registered photons over a pixel area  
25 is not large.

The pixel value  $p$  at some point  $X$  in a noisy image can be considered as a sum of a mean value  $P$ , which the pixel would have in a true image, without noise, and of fluctuation  $F$ , wherein the pixel value  $p$  is given by the formula:

30 
$$p = P + F.$$



The expression "mean value" is denoted by the symbol  $M$ , so that  $P = M(p)$ , and  $M(F) = 0$ . The main parameter of such noise, describing its strength, is dispersion  $D$ . The dispersion  $D(X)$  is defined as a mean value of the squared fluctuation for pixel  $X$ , which is given by the formula:

$$D(X) = M(F^2).$$

The quality of an image is usually characterized by the so-called signal-to-noise ratio ( $S/N$ ), which is actually defined as  $P^2/D$ . The noise reduction makes the dispersion  $D$  smaller and improves  $S/N$ .

The mean value  $M(FG)$  of the product of fluctuations  $F$ ,  $G$  of two pixel values  $p = P(X) + F$ ,  $g = P(Y) + G$  at different points  $X$ ,  $Y$  ( $Y$  may be the point with same coordinates as  $X$  but lying in a different image) is called covariance of values  $p$ ,  $g$ . This quantity together with dispersions of  $p$ ,  $g$  makes  $2 \times 2$  covariance matrix

$$V = \begin{pmatrix} V_{11} & V_{12} \\ V_{21} & V_{22} \end{pmatrix},$$

with elements,

$$V_{11} = M(F^2) = D(X),$$

$$V_{12} = V_{21} = M(FG),$$

$$V_{22} = M(G^2) = D(Y).$$

The strength of the mutual dependence of fluctuations  $F$ ,  $G$  is measured by the correlation coefficient  $C$ , which is given by the formula:

$$C = V_{12} / \sqrt{V_{11} V_{22}},$$

which may vary from -1 to 1. The values  $C = -1$  and  $C = 1$  correspond to complete dependence of fluctuations, so  $F$  and  $G$  are proportional and by knowing  $F$  one may thereby calculate  $G$ , and vice versa. The dispersion  $D$  of the linear combination

5  $\alpha p + \beta g$  of the pixel values  $p, g$  is expressed by the formula:

$$D(\alpha p + \beta g) = \alpha^2 V_{11} + \beta^2 V_{22} + 2\alpha\beta V_{12}.$$

The mean value is most often unknown and is approximately estimated by the average value over some number  $N$  of independently obtained values  $x_i$  of the same quantity  $x$ ,  
10 wherein the average value of  $x$  is given by the formula:

$$\text{Avr}(x) = \sum x_i w_i / \sum w_i,$$

where positive coefficients  $w_i$  are weights. If the weights are equal to one, which is adopted if  $x_i$  have same accuracy, the average of  $x$  is given by the formula:

15 
$$\text{Avr}(x) = \sum x_i / N.$$

For example, the true pixel value  $P(X)$  at point  $X$  may be estimated as  $\text{Avr}(p)$  of values  $p_i$  of pixels at points  $Y_i$  in some area around  $X$ , if there are reasons to think that true values  $P_i$  differ little from  $P(X)$ , or their deviations from  
20  $P(X)$  compensate each other. The dispersion  $D(X)$  may be estimated as the average of the squared deviations from  $\text{Avr}(p)$ , which is given by the formula:

$$D(X) \approx \text{Avr}((p - \text{Avr}(p))^2),$$

if there are reasons to think that the noise is of the same  
25 strength in the chosen area around  $X$ . Similarly, covariance  $V_{12}$  may be estimated as:

$$V_{12} \approx \text{Avr}((p - \text{Avr}(p))(g - \text{Avr}(g))).$$

The usual methods of noise reduction replace each pixel of an image by the average value over some area around a pixel. This area together with a table of coefficients, with which the pixel values are summed, is usually called a filter. A simple example of a filter is a square of 9 pixels, the values of which are summed with the same coefficient  $1/9$  when the average is calculated. Averaging with such filter diminishes the noise dispersion 9 times, but smears the image making each visible line in it 4 pixels wider and correspondingly decreasing its contrast. The methods described in the present invention achieve greater reduction of noise dispersion at the same smearing consequence, or reduce the smearing consequence for the same noise reduction.

A tomographic reconstruction is the calculation of the density of the object on some planes cutting the object using a plurality of X-ray pictures or NMR (Nuclear Magnetic Resonance) data. It is a complex procedure, reconstructing images with correlated noise.

The reconstruction of the densities of the bone and of the soft tissue is more simple and consists of calculation of two functions  $a(p,g)$ ,  $b(p,g)$  giving the densities of the bone and soft tissue as functions of pixel values  $p, g$  at point  $X$  in two X-ray images obtained with X-rays of different energies. The functions  $a(p,g)$ ,  $b(p,g)$  are usually obtained from calibration X-ray exposures of objects with known densities of bone and soft tissue equivalents. Both functions are very sensitive to small differences of pixel values  $p - g$ , so the calculated densities have larger noise dispersions and worse signal-to-noise ratio than the original X-ray images. The noise in the bone density image is strongly correlated with the noise in the soft tissue density image, where the correlation coefficient  $C$  is negative and close to  $-1$ .

A first method of noise reduction using property (a) of the true image (presence of smooth fragments) and property (b) of the noise (known dispersion) will now be described.

The first method reduces noise at each point X of an image by averaging the pixel values over a region R, wherein the averaging region R is dependent on X and is selected as the largest region around X, which includes only pairs of pixels Y, Z symmetrically placed with respect to X and having the half sums  $(p(Y) + p(Z))/2$  of values deviating from each other within the limits corresponding to the level of the noise in the image and to a user-defined tolerance preferences L for the noise-reduced image.

The largest averaging region R approximating the optimal one is found as follows.

Firstly, a selected pixel X is included into the region R. Then, the pairs of pixels  $Y = X - v$ ,  $Z = X + v$ , where v is a shift vector, symmetrical with respect to point X and touching the already filled part of the region R, are considered pair by pair and a check is made whether the squared difference of their half sum  $p(v) = (p(Y) + p(Z))/2$  from the average value of the pixels already included into R does not exceed the dispersion D of the noise present in the mentioned difference multiplied by some tolerance level L set by the user. If the pair of pixels passes the test, it is included into R. As long as the region R grows, the process continues with considering of pairs as described above. The process is stopped when no new pair of pixels passes the tests. Then the average pixel value over R is used as a value of pixel X in an image with reduced noise.

Better approximations of an optimal region R may be found in a similar way by inclusion of more tests for randomness of deviations of pixel values and tests for the presence near X

0071633-4100

5

The region R must be symmetric to eliminate the distortion of the image due to contribution of the gradient of true image intensity into the average value.

10

15

20

25

30

of the true image. In particular, this property has the above-mentioned test written as the formula:

$$(p(v) - \text{Avr}_v(X))^2 < D(X,v)L,$$

where  $\text{Avr}_v$  here denotes the average over all pixel pairs  
5 earlier included into  $R$  and  $D(X,v)$  stands for the dispersion of the difference  $p(v) - \text{Avr}_v(X)$ .

Dispersion  $D(X,v) \sim D(X) \cdot (1/2 + 1/n)$ , where  $n$  is a number of  
pixels in  $R$ , may be known from different sources: from  
analysis of earlier images obtained with the same technology,  
10 from the number of photons registered in case of Poisson  
statistics of noise, or from the image itself by means of the  
formula  $D(X,v) = \text{Avr}((p - \text{Avr}(p))^2)$ , where  $p = p(v)$  and  
averaging is done over all pixel pairs earlier included in to  
 $R$ . The estimation of  $D(X)$  and  $D(X,v)$  may be done in many ways  
15 and is not an integral part of the invention.

The details of the algorithm picking up the pairs of pixels  
tested for possible inclusion into region  $R$  may be different  
and are not the integral part of the present invention. The  
process of checking is mentioned solely to give a general  
20 idea how the method may be realized. Actually, in a tested  
algorithm, the order, in which the pairs of pixels were  
tested, was fixed so as to allow the region  $R$  to grow  
continuously, by one-pixel layers of square shape until the  
deviation checks were positive. Every time when a new pair  
25 was added to the region  $R$ , the pixels touching to this pair  
were marked as possible extensions of  $R$ . The next picked pair  
of pixels was first checked for being marked. If it was  
unmarked, it was skipped without other more time-consuming  
tests. When none of the pixels in a next completed square  
30 layer passed the tests, the process of expansion of the  
region  $R$  stops.

The purpose of the additional checks for randomness of deviations is intended to clear the region R from compact groups of pixels (and their symmetrical partners) which pass the tests for individual pairs, but which deviate collectively too much to one side. If deviations are random, the squared deviation of the average of K half sums of pixel pairs from the true value  $(P(X) - \text{Avr}_{kp}(v))^2$  may only exceed  $2D(X)/K$  in a few percent of cases. If a group of pixel pairs deviates more, its exclusion from the region R will most probably make the average over the region R closer to the pixel value  $P(X)$  of the true image. The check for the presence of certain suspected details is similar to the check above, but is more sensitive for deviation in groups of pixels of certain shapes.

The region R found in a one-pass process usually contains many holes, where most of the pixels do not deviate much, but at the time of their check during the first pass did not touch pixels already included into R. The revision of R with the account of points included afterwards and with slightly more liberal deviation test does not increase the size of R but makes it more solid.

The pixels in a borderline of a solid many-pixel region R should, normally, touch with 4 or 5 pixels belonging to this region. The rejection of peripheral points touching with less than 3 pixels belonging to the region R does not decrease significantly the number of pixels in the region R, but smoothes the borderline and decreases the risk of smearing distortions.

A second method of noise reduction using property (c) that the noise in the image is significantly correlated with the noise in other images will now be described.

The second method reduces noise at each point  $X$  of an image  $I_1$  correlated with the noise at a corresponding point  $Y$  of an image  $I_2$  with the variance-covariance matrix  $V$  for pixel values  $p(X, I_1)$ ,  $p(Y, I_2)$  by:

- 5 (1) obtaining from image  $I_2$  a noise reduced image  $I_3$  by any noise reduction method not using image  $I_1$ ;

- (2) calculating the estimate  $F(Y)$  given by the formula:

$$F(Y) = p(Y, I_2) - p(Y, I_3)$$

of the fluctuation of the pixel value at point  $Y$ ;

- 10 (3) calculating the estimate  $H(X, I_1)$  given by the formula:

$$H(X, I_1) = F(Y) \frac{V(p(X, I_1), p(Y, I_2))}{V(p(Y, I_2), p(Y, I_2))}$$

of fluctuation  $G(X, I_1)$  of pixel value  $p(X, I_1)$  in image  $I_1$ ; and

- (4) obtaining from image  $I_1$  a noise reduced image  $I_4$  by subtracting from each pixel value of image  $I_1$  the estimate of  
15 its fluctuation, which is given by the formula:

$$p(X, I_4) = p(X, I_1) - H(X, I_1).$$

If the matrix  $V$  as a function of  $X$  is known, implementation is straightforward and reduces to repeating calculations (2), (3), and (4) for all pixels  $X$ .

- 20 If the matrix  $V$  is not given, its estimate at each point  $X$  may be found by a standard method as average values over a small region around the point  $X$  and corresponding region around the point  $Y$  of products of deviations of pixel values from their average values over the same regions.

- 25 The second method reduces in image  $I_1$  only the part of its noise which is correlated with the noise in image  $I_2$  and does



not remove the part of noise in image  $I_1$  which is independent from the noise in image  $I_2$ . So the maximal coefficient of noise reduction by the second method is limited by the difference  $1 - C^2$ , where  $C$  is the correlation coefficient,

5 which is given by the formula:

$$C = \frac{V(p(X, I_1), p(Y, I_2))}{\sqrt{V(p(X, I_1), p(X, I_1))V(p(Y, I_2), p(Y, I_2))}}.$$

If  $C^2$  is close to 1.0, the noise reduction in image  $I_4$  may be very deep. If  $C^2$  is noticeably smaller than 1.0, image  $I_4$  still contains noticeable independent noise. This noise may  
10 be reduced by applying to image  $I_4$  other noise-reduction methods (including the first method).

The noise reduction by the second method has some specific consequence. It is related with the fact that image  $I_3$  obtained from image  $I_2$  contains smearing distortions. These  
15 distortions pass into estimates  $H$  and from them pass into the noise-reduced image  $I_4$ , where they look as a kind of shadows of boundaries of objects on image  $I_2$ .

Since images  $I_1$ ,  $I_2$  are different, the boundaries of image fragments in image  $I_1$  and image  $I_2$ , generally do not coincide  
20 and shadows of boundaries of fragments of image  $I_2$  do not smear details in image  $I_4$ . These shadows obscure details in image  $I_4$  much less than the original noise in image  $I_1$ , so small details in image  $I_1$  lost in the noise in image  $I_1$  become visible after such noise reduction. By contrast, usual  
25 noise-reduction methods make small details less visible after noise reduction.

The intensity and widths of mentioned shadows of image  $I_2$  in image  $I_4$  depend on the choice of the method and parameters of noise reduction for image  $I_3$ . The optimal choice of noise  
30 reduction for image  $I_2$  depends on the structure of images  $I_1$

and  $I_2$  and of preferences of the user of image  $I_4$ . The choice of the first method of the present invention for noise reduction in image  $I_2$  is advantageous since it reduces the shadows of image  $I_2$  obscuring the image  $I_4$ .

- 5 The noise remaining in image  $I_4$  can be further reduced by many methods. A comparison of image, obtained from image  $I_4$  after noise reduction by the first method, with a true clean image shows that, when the noise correlation is present, the combination of the second and the first method makes very  
10 deep noise reduction without noticeable distortions or smearing.

The roles of images  $I_1$  and  $I_2$  may be interchanged, so the noise may be reduced in image  $I_2$  by the second method as well.

- 15 In an experiment with two artificially constructed images  $I_1$ ,  $I_2$ , imitating images taken with high energy respective low energy X-rays, the noise was 95% correlated. To reduce noise in image  $I_2$ , the first method was used with an additional check sensitive to the systematic deviation of local  
20 intensity from the average one and reducing "shadows" of image  $I_2$  in image  $I_4$ .

- A comparison of image  $I_4$  and noise-reduced image, obtained from image  $I_1$  by the first method, gave the result that the first method is more efficient for large fragments (for  
25 background), while the second method is advantageous for small fragments and details.

A third method of noise reduction using properties (a), (b), (c), and property (d) that images are reconstructed from common source images (data) will now be described.

- 30 The third method reduces noise in images  $I_1$  and  $I_2$  reconstructed (computed) as known smooth functions  $I_1 =$

$a(S_1, S_2)$ ,  $I_2 = b(S_1, S_2)$  from source images  $S_1$ ,  $S_2$  with independent noise of known dispersion by combination of the first and the second method modified to exploit images  $S_1$ ,  $S_2$  and functions  $a$ ,  $b$  as follows:

5 (5) a noise reduced image  $I_3$  is obtained from image  $I_2$  by noise reduction by the first method, where the averaging region  $R$  is selected as the maximal region  $R$  around  $Y$ , which includes only the pairs of pixels symmetrically placed with respect to  $Y$  and; either

10 having the sums of values deviating from each other within the limits corresponding to the level of the noise in the image and to a tolerance preferences of the user of the noise-reduced image; or

corresponding to pairs of pixels in source images  $S_1$ ,  $S_2$   
 15 having the sums of values deviating from each other within the limits corresponding to the level of the noise in the images  $S_1$ ,  $S_2$  and to a tolerance preferences of the user of the noise-reduced image;

(6) the estimate  $F(Y)$  given by the formula:

20 
$$F(Y) = p(Y, I_2) - p(Y, I_3)$$

of the fluctuation of the pixel value at point  $Y$  is calculated;

(7) the covariance matrix  $V$  for pixel values  $p(X, I_1)$ ,  $p(Y, I_2)$  at points  $X$ ,  $Y$  on images  $I_1$ ,  $I_2$  is computed in linear  
 25 approximation as given by the formulae:

$$V(p(X, I_1), p(X, I_1)) = \left( \frac{\partial a}{\partial S_1} \right)^2 D_1 + \left( \frac{\partial a}{\partial S_2} \right)^2 D_2,$$

$$V(p(X, I_1), p(Y, I_2)) = \left( \frac{\partial a}{\partial S_1} \right) \left( \frac{\partial b}{\partial S_1} \right) D_1 + \left( \frac{\partial a}{\partial S_2} \right) \left( \frac{\partial b}{\partial S_2} \right) D_2,$$

$$V(p(Y, I_2), p(Y, I_2)) = \left( \frac{\partial b}{\partial S_1} \right)^2 D_1 + \left( \frac{\partial b}{\partial S_2} \right)^2 D_2,$$

where  $D_1$  and  $D_2$  are the noise dispersions in images  $S_1$ ,  $S_2$  at points  $Z$ ,  $T$  corresponding to point  $Y$ ;

- 5 (8) the estimate  $H(X, I_1)$  given by the formula:

$$H(X, I_1) = F(Y) \frac{V(p(X, I_1), p(Y, I_2))}{V(p(Y, I_2), p(Y, I_2))}$$

of fluctuation  $G(X, I_1)$  of pixel value  $p(X, I_1)$  in image  $I_1$  is calculated; and

- 10 (9) a noise reduced image  $I_4$  is obtained from image  $I_1$  by subtracting the estimate of fluctuation from each pixel value, wherein  $P(X, I_4)$  is given by the formula:

$$p(X, I_4) = p(X, I_1) - H(X, I_1).$$

- 15 The relations  $I_1 = a(S_1, S_2)$  and  $I_2 = b(S_1, S_2)$  between images are pixel-wise, that is the point  $X$  on image  $I_1$  corresponds uniquely to points  $Y$ ,  $Z$ ,  $T$  on images  $I_2$ ,  $S_1$ ,  $S_2$  respectively. So, these relations can be written for pixels as given by the formulae:

$$p(X, I_1) = a(p(Z, S_1), p(T, S_2)),$$

$$p(Y, I_2) = b(p(Z, S_1), p(T, S_2)).$$

- 20 The implementation is straightforward and consists of performing operations (5)-(9) for all pixels of image  $I_1$ . The simplest implementation of point (5) is to check only the difference between the sum of values and the double value of a central pixel (the check is done both for image  $I_1$  and for

the source images  $S_1, S_2$ ). The use of source images in the step (5) usually makes the quality of the region  $R$  found by the pixel-selection process described in the simplest implementation of the first method good enough without additional checks and boundary smoothing.

More advanced implementation of point (5) may check as well the deviation of the average source value from the average of the values of several pixel pairs touching the pixel pair in question. Such test locates more accurately the boundaries of the region  $R$ .

The most time-consuming step of the third method is the computation of the matrix  $V$  at all points. However, the ratio of its elements used in step (8) can be computed and tabulated beforehand as a two-argument function. In this case the computation of the matrix  $V$  is done quickly by interpolation and the whole noise reduction procedure takes about the same time as the calculation of image  $I_1$  from images  $S_1, S_2$ .

The smooth fragments of the source images correspond to smooth fragments on reconstructed images (but not vice versa, since reconstructed images contain smaller number of details than the source ones). Since the source images have relatively small noise, their use helps to define reliably the part of the region  $R$ , which does not contain details of the true image able to distort the average value, and helps to reduce statistical uncertainties of the boundaries. This makes the third method applicable in cases of very noisy (reconstructed) images, for which all other methods of noise reduction become inefficient.

In cases of less noisy images, when different noise reduction methods are applicable, the third method makes smearing distortions in image  $I_3$  smaller, and image  $I_4$  cleaner from

shadows of fragment boundaries in image  $I_2$ . These shadows may become even indistinguishable.

The squared correlation coefficient for reconstructed images often exceeds 0.90 and noise dispersion can be reduced in image  $I_4$  more than a dozen times, if matrix  $V$  is known accurately enough. The knowledge of reconstruction functions  $a, b$  gives the possibility to compute  $V$  and the ratio between fluctuations  $H$  and  $F$  more accurately than by analysis of images  $I_1, I_2$  themselves and achieve the noise reduction close to the theoretical limit.

In an experiment of the third method, an image  $I_1$  and an image  $I_2$  were reconstructed from two source images of simulated X-ray pictures of the combination of bone and tissue.

Reconstruction greatly amplifies the small intensity-dependent noise present in a source image (image  $S_1$  or  $S_2$ ), so the noise in images  $I_1, I_2$  was large and boundaries of fragments were smeared. This noise in  $I_1$  was 95% correlated with the noise in  $I_2$ . In this case, difficult to the first method, the third method remained efficient and gave an image where the "shadows" of other image are noticeable, but the noise reduction is deep and small details are reproduced without any smearing.

Preferably, the methods of the present invention is performed by software code, located in the internal memory of a computer, and executed by a processor of that computer.

It will be obvious that the present invention may be varied in a plurality of ways. Such variations are not to be regarded as departure from the scope of the present invention. All such variations as would be obvious to one

Parameter	Value	Unit
Temperature	25.0	°C
Pressure	1.0	atm
Flow rate	1.0	L/min
Wavelength	254	nm
Scan rate	10	nm/min
Integration time	10	s
Injection volume	10	μL
Mobile phase	Water	
Stationary phase	C18	
Column length	150	cm
Column diameter	4.6	mm
Particle size	5	μm
Retention time	10.5	min
Peak area	1234567	Area Units
Peak height	123456	Height Units
Peak width	12345	Width Units
Peak symmetry	1.234	
Peak resolution	1.234	
Peak purity	1.234	
Peak identification	1.234	
Peak classification	1.234	
Peak quality	1.234	
Peak status	1.234	
Peak comment	1.234	
Peak description	1.234	
Peak notes	1.234	
Peak history	1.234	
Peak metadata	1.234	
Peak analysis	1.234	
Peak results	1.234	
Peak summary	1.234	
Peak details	1.234	
Peak information	1.234	
Peak data	1.234	
Peak output	1.234	
Peak report	1.234	
Peak document	1.234	
Peak file	1.234	
Peak path	1.234	
Peak name	1.234	
Peak title	1.234	
Peak author	1.234	
Peak date	1.234	
Peak time	1.234	
Peak location	1.234	
Peak category	1.234	
Peak type	1.234	
Peak format	1.234	
Peak version	1.234	
Peak status	1.234	
Peak comment	1.234	
Peak description	1.234	
Peak notes	1.234	
Peak history	1.234	
Peak metadata	1.234	
Peak analysis	1.234	
Peak results	1.234	
Peak summary	1.234	
Peak details	1.234	
Peak information	1.234	
Peak data	1.234	
Peak output	1.234	
Peak report	1.234	
Peak document	1.234	
Peak file	1.234	
Peak path	1.234	
Peak name	1.234	
Peak title	1.234	
Peak author	1.234	
Peak date	1.234	
Peak time	1.234	
Peak location	1.234	
Peak category	1.234	
Peak type	1.234	
Peak format	1.234	
Peak version	1.234	
Peak status	1.234	
Peak comment	1.234	
Peak description	1.234	
Peak notes	1.234	
Peak history	1.234	
Peak metadata	1.234	
Peak analysis	1.234	
Peak results	1.234	
Peak summary	1.234	
Peak details	1.234	
Peak information	1.234	
Peak data	1.234	
Peak output	1.234	
Peak report	1.234	
Peak document	1.234	
Peak file	1.234	
Peak path	1.234	
Peak name	1.234	
Peak title	1.234	
Peak author	1.234	
Peak date	1.234	
Peak time	1.234	
Peak location	1.234	
Peak category	1.234	
Peak type	1.234	
Peak format	1.234	
Peak version	1.234	
Peak status	1.234	
Peak comment	1.234	
Peak description	1.234	
Peak notes	1.234	
Peak history	1.234	
Peak metadata	1.234	
Peak analysis	1.234	
Peak results	1.234	
Peak summary	1.234	
Peak details	1.234	
Peak information	1.234	
Peak data	1.234	
Peak output	1.234	
Peak report	1.234	
Peak document	1.234	
Peak file	1.234	
Peak path	1.234	
Peak name	1.234	
Peak title	1.234	
Peak author	1.234	
Peak date	1.234	
Peak time	1.234	
Peak location	1.234	
Peak category	1.234	
Peak type	1.234	
Peak format	1.234	
Peak version	1.234	
Peak status	1.23	

## CLAIMS

1. A method for reduction of noise in an image including a plurality of pixels, comprising averaging pixel values over a region (R), characterized by the steps of:

- 5 - adding a selected pixel to the region (R);
- grouping pixels adjacent the region (R) in pairs, wherein the pixels of each pair being oppositely located with respect to said selected pixel;
- adding said pairs, pair by pair, to the region (R) in  
10 dependence on that the squared difference of the selected pixel value from the pairs half sums does not exceed the dispersion (D) of the noise of said difference multiplied by a tolerance level (L);
- repeating said step of grouping and said step of adding  
15 said pairs until that, in said step of adding said pairs, the condition for adding said pairs is not fulfilled for any pair;
- averaging the pixel values of said region (R); and
- using the thus averaged pixel value for said selected pixel  
20 in reconstruction of said image.

2. The method as claimed in claim 1, wherein said step of grouping excludes grouping of pixels previously being grouped in pairs.

3. The method as claimed in claim 1, wherein said step of  
25 adding said pairs excludes pairs that do not touch any of the pairs already included in said region (R).

4. The method as claimed in claim 1, 2 or 3, wherein said method is performed a second time and wherein said step of



grouping during said second time only includes pixels rejected during the first performance of said method.

5 5. The method as claimed in any of claims 1-4, wherein said step of adding said pairs is performed in dependence on that the squared difference of an average of pixel values in the region (R) from the pairs half sum does not exceed the dispersion (D) of said difference multiplied by a tolerance level (L).

10 6. A method for reduction of noise in an image including a plurality of pixels, characterized by the steps of:

- obtaining a noise reduced value of a first pixel;
- calculating an estimate of the fluctuation of said noise reduced value of said first pixel;
- calculating an estimate of the fluctuation at a second pixel, wherein said fluctuation of said second pixel is correlated to said fluctuation of said first pixel; and
- obtaining a noise reduced value of said second pixel by subtracting said fluctuation at said second pixel.

20 7. The method as claimed in claim 6, wherein the absolute value of said correlation is at least 0.8, preferably 0.9, and more preferably 0.95.

8. The method as claimed in claim 6 or 7, wherein said first and said second pixels are located in different images.

25 9. A method for reduction of noise in an image including a plurality of pixels, comprising averaging pixel values over a first region (R) around a selected pixel (X), characterized by the steps of:

- finding a second pixel (X1) corresponding to said selected pixel (X);

- adding said second pixel (X1) to a second region (R1);

- grouping pixels adjacent the second region (R1) in pairs,  
5 wherein the pixels of each pair being oppositely located with respect to said selected pixel;

- adding said pairs, pair by pair, to the second region (R1) in dependence on that the squared difference of the selected pixel value from the pairs half sums does not exceed the  
10 dispersion (D) of the noise of said difference multiplied by a tolerance level (L);

- repeating said step of grouping and said step of adding said pairs until that, in said step of adding said pairs, the condition for adding said pairs are not fulfilled for any  
15 pair;

- averaging the pixel values of the first region (R), which corresponds to the second region (R1); and

- using the thus averaged pixel value for the selected pixel (X) of said first region (R) in reconstruction of said image.

20 10. The method as claimed in claim 9, wherein said step of grouping excludes pixels previously grouped in pairs.

11. The method as claimed in claim 9 or 10, wherein said dispersion (D) is based on the region (R1) instead of said selected pixel.

25 12. The method as claimed in any of claims 9-11, wherein said step of adding said pairs is performed in dependence on that the squared difference of an average of pixel values in the region (R1) from the pairs half sum does not exceed the

dispersion (D) of said difference multiplied by a tolerance level (L).

13. The method as claimed in any of claims 9-12, wherein said second region (R1) is located in an image, which is different  
5 than the image wherein said first region (R) is located.

14. The method as claimed in any of claims 9-13, wherein said noise reduced image is further noise reduced by the method according to any of claims 6-8.

15. The method as claimed in any of claims 9-14, wherein said  
10 noise reduced image is further noise reduced by the method according to any of claims 1-5.

16. A computer program product directly loadable into the internal memory of a computer, said computer program product comprising software code portions for performing the method  
15 as claimed in any of claims 1-15 when said computer program product is run on said computer.

**ABSTRACT**

09716293-112400  
The present invention relates to a method for reduction of noise in an image including a plurality of pixels, comprising averaging pixel values over a region (R), comprising the

5 steps of: adding a selected pixel to the region (R); grouping pixels adjacent the region (R) in pairs, wherein the pixels of each pair being oppositely located with respect to said selected pixel; adding said pairs, pair by pair, to the region (R) in dependence on the squared difference of the

10 selected pixel value from the pairs half sums does not exceed the dispersion (D) of the noise of said difference multiplied by a tolerance level (L); repeating said step of grouping and said step of adding said pairs until that, in said step of adding said pairs, the condition for adding said pairs is not

15 fulfilled for any pair; averaging the pixel values of said region (R); and using the thus averaged pixel value for the selected pixel of said region (R) in reconstruction of said image.

**BIRCH, STEWART, KOLASCH & BIRCH, LLP**P.O. Box 747 • Falls Church, Virginia 22040-0747  
Telephone: (703) 205-8000 • Facsimile: (703) 205-8050PLEASE NOTE:  
YOU MUST  
COMPLETE THE  
FOLLOWING**COMBINED DECLARATION AND POWER OF ATTORNEY  
FOR PATENT AND DESIGN APPLICATIONS**

As a below named inventor, I hereby declare that: my residence, post office address and citizenship are as stated next to my name; that I verily believe that I am the original, first and sole inventor (if only one inventor is named below) or an original, first and joint inventor (if plural inventors are named below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

NOISE REDUCTION IN IMAGES

Insert Title:

Fill in Appropriate  
Information -  
For Use Without  
Specification  
Attached:

the specification of which is attached hereto. If not attached hereto,

the specification was filed on \_\_\_\_\_ as  
 United States Application Number \_\_\_\_\_;  
 and amended on \_\_\_\_\_ (if applicable) and/or  
 the specification was filed on \_\_\_\_\_ as PCT  
 International Application Number \_\_\_\_\_; and was  
 amended under PCT Article 19 on \_\_\_\_\_ (if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56.

I do not know and do not believe the same was ever known or used in the United States of America before my or our invention thereof, or patented or described in any printed publication in any country before my or our invention thereof or more than one year prior to this application, that the same was not in public use or on sale in the United States of America more than one year prior to this application, that the invention has not been patented or made the subject of an inventor's certificate issued before the date of this application in any country foreign to the United States of America on an application filed by me or my legal representative or assigns more than twelve months (six months for designs) prior to this application, and that no application for patent or inventor's certificate on this invention has been filed in any country foreign to the United States of America prior to this application by me or my legal representatives or assigns, except as follows.

I hereby claim foreign priority benefits under Title 35, United States Code, §119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

**Prior Foreign Application(s)****Priority Claimed**Insert Priority  
Information:  
(if appropriate)

<u>0003608-7</u> (Number)	<u>Sweden</u> (Country)	<u>October 6, 2000</u> (Month/Day/Year Filed)	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No
_____ (Number)	_____ (Country)	_____ (Month/Day/Year Filed)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
_____ (Number)	_____ (Country)	_____ (Month/Day/Year Filed)	<input type="checkbox"/> Yes	<input type="checkbox"/> No
_____ (Number)	_____ (Country)	_____ (Month/Day/Year Filed)	<input type="checkbox"/> Yes	<input type="checkbox"/> No

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States provisional applications(s) listed below.

Insert Provisional  
Application(s):  
(if any)

_____ (Application Number)	_____ (Filing Date)
_____ (Application Number)	_____ (Filing Date)

All Foreign Applications, if any, for any Patent or Inventor's Certificate Filed More than 12 Months (6 Months for Designs) Prior to the Filing Date of This Application:

Country	Application Number	Date of Filing (Month/Day/Year)
_____	_____	_____
_____	_____	_____

Insert Requested  
Information:  
(if appropriate)

I hereby claim the benefit under Title 35, United States Code, §120 of any United States and/or PCT application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States and/or PCT application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is material to the patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

Insert Prior U.S.  
Application(s):  
(if any)

_____ (Application Number)	_____ (Filing Date)	_____ (Status - patented, pending, abandoned)
_____ (Application Number)	_____ (Filing Date)	_____ (Status - patented, pending, abandoned)

## Attorney Docket No.

I hereby appoint the following attorneys to prosecute this application and/or an international application based on this application and to transact all business in the Patent and Trademark Office connected therewith and in connection with the resulting patent based on instructions received from the entity who first sent the application papers to the attorneys identified below, unless the inventor(s) or assignee provides said attorneys with a written notice to the contrary:

Raymond C. Stewart	(Reg. No. 21,066)	Terrell C. Birch	(Reg. No. 19,382)
Joseph A. Kolasch	(Reg. No. 22,463)	James M. Slattery	(Reg. No. 28,380)
Bernard L. Sweeney	(Reg. No. 24,448)	Michael K. Mutter	(Reg. No. 29,680)
Charles Gorenstein	(Reg. No. 29,271)	Gerald M. Murphy, Jr.	(Reg. No. 28,977)
Leonard R. Svensson	(Reg. No. 30,330)	Terry L. Clark	(Reg. No. 32,644)
Andrew D. Meikle	(Reg. No. 32,868)	Marc S. Weiner	(Reg. No. 32,181)
Joe McKinney Muncy	(Reg. No. 32,334)	Donald J. Daley	(Reg. No. 34,313)
John W. Bailey	(Reg. No. 32,881)	John A. Castellano	(Reg. No. 35,094)
Gary D. Yacura	(Reg. No. 35,416)		

Send Correspondence to:

**BIRCH, STEWART, KOLASCH & BIRCH, LLP**

or **Customer No. 2292**

P.O. Box 747 • Falls Church, Virginia 22040-0747

Telephone: (703) 205-8000 • Facsimile: (703) 205-8050

PLEASE NOTE:  
YOU MUST  
COMPLETE  
THE  
FOLLOWING:

↓

Full Name of First  
or Sole Inventor:  
Insert Name of  
Inventor  
Insert Date This  
Document is Signed

Insert Residence  
Insert Citizenship

Insert Post Office  
Address

Full Name of Second  
Inventor, if any:  
see above

Full Name of Third  
Inventor, if any:  
see above

Full Name of Fourth  
Inventor, if any:  
see above

Full Name of Fifth  
Inventor, if any:  
see above

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

GIVEN NAME/FAMILY NAME Skiff Sokolov		INVENTOR'S SIGNATURE <i>Skiff Sokolov</i>	DATE* 2000. 10. 12
Residence (City, State & Country) Lidingö, Sweden		CITIZENSHIP Russian	
POST OFFICE ADDRESS (Complete Street Address including City, State & Country) Kostervägen 5, SE-181 35 Lidingö, Sweden			
GIVEN NAME/FAMILY NAME		INVENTOR'S SIGNATURE	DATE*
Residence (City, State & Country)		CITIZENSHIP	
POST OFFICE ADDRESS (Complete Street Address including City, State & Country)			
GIVEN NAME/FAMILY NAME		INVENTOR'S SIGNATURE	DATE*
Residence (City, State & Country)		CITIZENSHIP	
POST OFFICE ADDRESS (Complete Street Address including City, State & Country)			
GIVEN NAME/FAMILY NAME		INVENTOR'S SIGNATURE	DATE*
Residence (City, State & Country)		CITIZENSHIP	
POST OFFICE ADDRESS (Complete Street Address including City, State & Country)			
GIVEN NAME/FAMILY NAME		INVENTOR'S SIGNATURE	DATE*
Residence (City, State & Country)		CITIZENSHIP	
POST OFFICE ADDRESS (Complete Street Address including City, State & Country)			
GIVEN NAME/FAMILY NAME		INVENTOR'S SIGNATURE	DATE*
Residence (City, State & Country)		CITIZENSHIP	
POST OFFICE ADDRESS (Complete Street Address including City, State & Country)			

\*DATE OF SIGNATURE